Connecting Dwellers to Building Performance and Weather Data through Sustainable Automation Systems

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Abstract. The paper presents a prototype for a Home Automation and Information Systems (HAIS) applied to an existing dwelling, the Florianopolis House, with the potential to address building performance and user behavior towards a more sustainable way of living. Home information and automation systems based on a great variety of sensors, associated with local weather stations and climate forecast databases can significantly impact the construction of more sustainable habits in home dwellers. Monitoring the weather variations, building’s performance and the impact each resident’s activity in energy and water consumption is a powerful tool for the dwellers’ awareness and can provide a significant impact on residents’ reconnection with the natural cycles. The development of the graphic interface is highlighted as a critical issue for the communication of building performance, weather data and actuators control.

Keywords. Home automation system; user behavior; weather data; graphic interface; building performance.

INTRODUCTION
Climate change awareness and the need to reduce the environmental impact has been widely discussed and accepted in the last decades. Throughout the world, buildings are responsible for one of the most significant portions of the environmental impact, energy use, water consumption and CO₂ emissions. Although we have generally accepted the need for a more sustainable society and for a major change in our environmental impact, statistics display opposed numbers. From 1984 to 2004, “primary energy has grown by 49% and CO2 emissions by 43%, with an average annual increase of 2% and 1.8% respectively” (Pérez-Lombard, Ortiz and Pout, 2007). World Annual growth in total residential electricity consumption from 1990 to 2006 was 3.4% and annual growth in electricity consumption per capita from 1995 to 2005 was 2.0%. The countries that are not members of the Organisation for Economic Co-operation and Development (OECD) responded for a greater part of these growths: 6.1% and 4.5% respectively. Brazilian annual residential demand for electricity between 1990 and 2005 has risen by an average of 3.6% and electricity consumption per capita increased 3.1% between 1990 and 2000. These numbers illustrates a growing number of households with access to electricity. However, they represent mostly the increase of electricity consumption by individual dwellers (IEA, 2009; Eletrobras, 2007). Residential electrical consumption in Brazil has risen from 22.4% in 2002 to 23.6% in
2011. However, Brazilian residential sector has diminished its participation in total energy consumption between 11.6% in 2002 to 9.5% in 2011 (MME, 2012). Economic conditions and severe climates significantly influence residential sector consumption. North American dwellings consume 22% of the final energy use. European countries residences respond, in average, for 26%, UK for 28% while Spain for 15%. HVAC is generally the largest energy end use in European and North American Countries (IEA, 2009). In Brazil, inexpensive and inefficient electrical showerheads are extensively used in low income housing and significantly impact residential electrical consumption. Hot showers respond for 24% of average electrical consumption in Brazilian homes, refrigerators for 22%, HVAC 20%, lighting 14% and TVs 9% (Eletrobras, 2007).

The International Energy Agency estimates an annual growth of energy used in buildings, until 2030, at an average rate of 1.5% (Pérez-Lombard et al., 2007). The use of renewable sources of energy could reduce the impact of this consumption increase. However, it is important to consider the actual reduction of energy consumption, in order to preserve finite resources, lower costs for business and consumers and achieve our goals quicker. Two directions could support the reduction of energy consumption: more efficient home equipment and technologies in general and user behavior. Some authors suggest that house and its equipment would respond for half of the energy consumption, while the residents’ behavior would account for the other half (Schipper, 1989). Others consider that individual behavior may vary dwelling energy consumption up to 300%, even considering differences in houses and families (Socolow, 1978).

Several authors defend the building as an educational device (Orr, 1997; Rohwedder, 2004; Janda, 2011). Orr (1997) identifies the buildings’ pedagogic capacity to teach - or unteach - their users about our society disconnection from the environment. However, he also provides directions to explore buildings as learning sustainable tools. On the other side, Kathryn Janda (2011) recognizes that building professionals, particularly architects, should lead towards relevant changes in energy reduction related to users’ behavior. According to her, education is the key instrument.

This paper aims to present a prototype for a Home Automation and Information Systems (HAIS) applied to an existing dwelling, the Florianopolis House, with the potential to address building performance and user behavior towards a more sustainable way of living. The first Brazilian entry at the Solar Decathlon academic competition raised several issues addressed in this paper and inspired the development of the Florianopolis House HAIS. The Brazilian team has envisaged the Ekó House for the Solar Decathlon Europe 2012 as a Brazilian approach towards an integral house: a house that could bring about human prosperity without harming nature.

A highly efficient solar house appears to be economically prohibitive for most people in a country that has a construction industry based on cheap labor and traditional methods, has a relatively low-cost energy, spends nearly no energy for home heating, and despite the economic growth, has a great portion of the population living with very low economic resources.

The Ekó Houses are temporary homes or lodges that help keeping remote communities – not attended by an electric grid – in their places. They should act as educational devices, affording a sustainable living experience for their guests. The costs of the temporary house could be shared by a greater number of individuals, and the house education benefits will be greater than if it would be designed for private owners. In addition to having a close contact with the wild natural environment and local community tradition, the guests would be aware of the impact of each activity they perform and choose habits they could change, in order to produce a relevant reduction of their environmental impact. The automation and information system is critical to afford the environmental and energy impact data of guests’ activities and its relationships with the natural cycles [1].
Connecting weather data from a local station to the system was one of the team’s goals. The HAIS for the Florianopolis House has developed this concept integrating through the graphic interface the house performance and control with weather data and local forecast.

THE FLORIANOPOLIS HOUSE
The Florianopolis House is a beach house, located in the southern Brazilian region, in a warm humid climate, with significant temperature variations during the day (Figure 1). The house is based on traditional brick wall, constructed in two layers with glass wool insulation in the void space between them. The house has a porch on the north façade with sliding wooden panel screens. These panels protect the openings from the summer sun, allowing both the passage of the cool breeze and the warm sun in the colder months. The front façade faces east and most rooms open to the northern sun and towards a large swimming pool. The pool reflects a strip of bamboos that protect the neighbor’s view. It highlights the rain drops of the common rainy days, support rainwater collection and functions as a swimming lap.

The house has an installed 3kW photovoltaic panels on the roof, shared with a sand based green roof. The sand gardens reproduce the local environment with dunes’ vegetation. The sand also helps to filter the water collected for reuse. The HAIS controls the exterior lighting, internal safety lighting, water heater, water pumps, motorized windows and a security alarm system.

Rainwater
The use of rainwater is an important feature of the Florianopolis House. Rainwater is collected through two independent systems. Although the systems are combined in one single tank, it is possible to select the systems that are collected or discarded. One of the systems is constituted by the swimming pool, with 45m² of surface area of cleaner and treated water, while the second and larger system has 150m² and collects the water from the roof sand garden, the photovoltaic panels and roof tiles. Rainwater is used for toilet water, watering plants, garage usage and washing recycling waste. Rainwater is directed related to weather cycles. Thus, the HAIS is an important tool to relate stored rainwater and weather forecast. Considering this data, one can decide whether postponing or anticipating an activity or deciding which systems should be used to collect the water. Since the swimming pool is daily filtered by a free-chlorine treatment, its water is better suited to activities that require dwellers’ manipulation.

Changes on dwellers’ habits, however, are more impacted by water overall consumption and rain fall. Water consumption is presented to the users as bar graphs with three variables per hour: current consumption, consumption in the previous day and month average (Figure 2). The month average is a
relevant reference, but one can easily compare differences in use between the current and previous day to experiment habit changes and verify its impact in water consumption. Additionally, numeric data informs overall water consumption and rain fall in the current day, week and month. The influences of rain fall and correlations with the progression and savings on water consumption are highlighted by these numbers. Comparing data is important in two different stages. First, householders compare the three levels of data day’s hour, previous day and week to understand the water quantity spent in specific tasks and then, if to follow the savings achievements. Since water quantity is not directly related to one single task, but to the entire house, one needs to verify other possible uses at that time, to estimate the water spent in each task. After that, it is easier to follow data and relate tasks, rain fall and savings. Providing data through a clear interface is critical to stimulate that households follow their savings and habit changes. Besides that, it is important that each person in the house manage their preferences in order to verify the importance of their changes related to the savings. Changes should be measured and decided individually. Many times it is easier for one person to change a specific habit that is more difficult for another. The latter could achieve similar savings changing other habits.

In addition to potable water savings, studies have demonstrated the impact of rain water usage in the amount of electrical energy reduction by the public water and sewage systems (Vieira, 2012; Ghisi, Cardoso, and Rupp, 2012). Vieira has focused his research in low-income housing but his findings that the use of rainwater, without any other water saving strategy, have responded for 0,86 kWh/m³ of collected rainwater, should equally apply to higher income houses.

The green roof has an irrigation system, based on water reuse and controlled by the automation system, which provides evaporative cooling in hot sunny days. Water reuse tasks, such as watering plants may be balanced with the amount of water collected in the tanks and indicated by level sensors and rainfall prediction.

**Hot water**

Electricity is the primary source of water heating for 73% of the Brazilian households. Electrical showerheads have a low purchasing price and relatively simple installation. Therefore, this inefficient device is widely used in residential and represents an average of 22% of the monthly bill. It is the highest-power device in most homes with the greatest impact on residential electrical consumption. The entire country has high irradiation levels, representing a great, although underutilized, potential for solar energy (Naspolini, Militão, and Rüther, 2010). Similarly to rainwater, solar heating has a straight connection to weather cycles and providing meaningful informa-
Explanation to the users is critical to increase efficiency. Few systems provide information about stored heat and people waste water, verifying the stored temperature, or energy, unnecessarily turning on the electrical backup system. The Florianopolis House HAIS design interface for water heating highlights pedagogic graphic information about the system, sensors’ temperature and weather forecast (Figure 3). Residential consumption has a great influence in the country energy peak, between 18:00 and 21:00, particularly because of evening showers. Instead of setting up the electrical boiler to turn on, one can verify stored temperature online and remotely turning the system on only if really necessary. Some tasks, such as washing the dishes, can be delayed or even a longer shower could be taken if forecast conditions are favorable. The visualization of the system performance is particularly useful to provide information about the overall infrastructure and functioning of the heating system. Understanding how the system operates increases the chances for a more efficient and sustainable use of water and electrical energy. Hot water tasks and the use of electric water heater are also balanced with sunny days’ prediction.

**Electricity management**

Variations of water provision by water utility company, requires that Brazilian houses have individual water tanks to accumulate necessary potable water. The water tank located on the roof and the service rooms are covered by twenty photovoltaic modules. Each module use amorphous, microcrystalline
silicon thin film technology with 142w of nominal power output.

Similarly to water consumption, the HAIS provides overall electrical consumption and generation data through bar graphs with three variables per hour: current consumption/generation, consumption/generation in the previous day and month average for both data. As for water consumption, householders usually receive their monthly consumption through the energy bill. They are seldom stimulated to examine their energy consumption and to elaborate savings strategies (Allen and Janda, 2006). Although real-time consumption feedback is provided (Figure 4), the bar graphs are more important to visualize historical data and identify in overall consumption the impact of specific tasks.

THE HOME AUTOMATION AND INFORMATION SYSTEM AND THE LOCAL SUPERVISORY CONTROL AND DATA ACQUISITION

The open source supervisory control and data acquisition (SCADA) system is a critical component for the success of the Florianopolis House HAIS. The open supervisory (SCADABR) has been developed at the Federal University of Santa Catarina for a great variety of uses. The first version of the system was launched five years ago and the authors try to keep it as broad as possible. Choosing an open source tool was one of the goals of our research group. It applies directly to one of the objectives of this HAIS research project, which is the testing of possibilities for sustainable automation solutions for low-income housing.
The SCADA system integrates the controlled components with different sensors and weather data and a graphic interface is currently being refined to facilitate data visualization, supporting more sustainable dwellers’ choice (Haeffner and Casalegno, 2009). The network is based on I2C technology, with around 700 meters of Cat5e cable to connect buttons, sensors, keypads and remote extension modules. The topology supports the required interconnections reducing delay responses. Each additional module or sensor into the bus adds milliseconds to the complete network scan. The project should be sized to meet time response expectations, which are less than 275ms. The ideal system delay is close to 150ms, to give an instantaneous feedback feeling. The system runs on a locally developed Programmable Logic Controller (PLC). The main controller integrates all sensors and actuators of the entire house. A low level (LADDER) program runs within the controller, which gives autonomy to repetitive and crucial tasks such as opening and closing the motorized windows according to the current local weather.

Several passive systems are controlled by the automation system or supported by the supervisory through sensors and weather data. Three motorized windows, regulated by the automation system, open towards the south, above the green roof, to extract hot air. The weather station and four other temperature sensors measure the temperature outside and in the different levels of the house, indicating the house performance and when the windows should be opened. In addition to that, the windows automatically close when rain is combined with south wind, to avoid infiltrating rain. The house windows offer several other alternatives for cross ventilation, which are also highlighted in the supervisory interface and verified by magnetic sensor located on the windows’ frame.

Data visualization is the focus of the current work and is critical for a successful and sustainable use of weather and building performance data. House performance data increasingly adds complexity for the supervisory interface. Thus, data has to be organized by its hierarchy importance relating it to different dwellers understandings (Bermúdez and Agutter, 2005).

The interface integrates numeric information, such as air temperature, with scalable vector graphics (svg). Therefore, one easily and quickly distinguishes temperature variation in different areas of the house as well as outside temperature. The interface is developed to be optimally visualized on an iPad or computer screen, although it can be easily controlled by the user through a smart phone. It presents the house in three background images generated from a 3D Revit model. The background images use the same perspective viewpoint and exchange from one external image (Figure 4), and two different sections (Figure 2 and 3), whenever information is clearer displayed. Data is organized in four main groups: energy, water, weather and security and background image changes also according to the menu item.

Some initiatives focus automation and information systems towards more sustainable houses (Kotsopoulos et al., 2012; Paetz et al., 2012). However, most of the current systems are still directed to automate routine tasks, such as turning on a set of lamps simultaneously, in order to simplify the daily home activities or leisure oriented, usually through media integration. Cost reductions in electronic equipments suggest a great potential for sustainable automation systems, even for low income dwellings. Inexpensive microcontrollers such as Arduino are capable to perform simple, but relevant tasks in this field connecting sensors and actuators.

Most residential technologies directed to increasing energy efficiency have a limited impact if not counting on the users’ contribution. Education is a primary source of promoting significant changes. The relationship between technology and home users is decisive for the house performance and sustainability. Some tasks may be automated, but the most relevant actions are the informed and sustainable decisions taken by the users (Darby, 2006).
Even the houses built for the Solar Decathlon competitions need an informed user in order to perform efficiently.

**EDUCATING THE DWELLERS**

Janda argues that the decisions which affect the way people use their buildings leading to over-consumption relates mostly to information deficit and their own living habits, practices and norms. The importance of information and energy feedback is defended mostly by policy and energy research communities. On the other side, studies confirm that feedback reduction is usually limited to 15%, depending if data is processed by the utilities and sent to the customers – indirect feedback, or available on demand – direct feedback. Several authors, mostly from social sciences, advocate that users’ behavior plays a much more relevant and complex role in this aspect (Janda, 2011).

Energy feedback devices, used by most researchers, are available on the market. They are usually direct feedback systems, centrally located in the residences and present energy data through a display and are not widely accepted or understood by users. We have taken a different approach focusing first the building performance to educate users about their houses systems. Graphic information should support understanding external resources (energy and water, for example) used for different activities and internal comfort. A great amount of resources wasted reflects the distance between householders and their home systems.

Primitive communities have developed in the course of history, technology to provide comfort conditions to their homes. These technologies were based primarily on close relationship the communities had with nature cycles. Their houses ingeniously responded to each region climate conditions. However, buildings’ comfort conditions, obtained through technological development, have progressively provided a separation between its residents and the cycles of nature. One no longer needs to worry much about climate variations, due to air conditioning systems, lighting, water heating, insulation, among other technologies, usually based on high-energy demand.

Home information and automation systems based on a great variety of sensors, associated with local weather stations and climate forecast databases have a potential to impact the construction of more sustainable habits in home dwellers. Monitoring the weather variations, building’s performance and the impact each resident’s activity in energy consumption and water is a powerful tool for the dwellers’ awareness and can provide a significant impact on residents’ reconnection with the natural cycles.

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